Synthetic Aperture Radar Sensors: Viable for Marine Oil Spill Response?

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Abstract

Space borne Synthetic Aperture Radars (SARs) have been used to observe and track the movement of marine oil spills for several years. SAR sensors possess many desirable characteristics for use in oil spill monitoring including; a wide field-of-view, foul weather independence, and day/night capabilities. On the other hand, spill response personnel have frequently been faced with some of the shortcomings of SAR sensors, sometimes unwittingly. Shortcomings of early space borne SAR sensors include: low spatial resolution, long revisit times, no positive means of oil detection, confusion with several false targets, and a limited wind speed "window" in which observation of oil is possible. The next generation of SAR sensors is currently coming on-stream and their enhanced capabilities can address some of the concerns voiced by spill response personnel. This paper will review the history of the use of SAR sensors as marine oil spill response tools, and illustrate some case studies where the use of SAR imagery has benefited.

1 Introduction

A number of novel Synthetic Aperture Radar (SAR) satellite sensors have recently been or will be launched by various international remote sensing/earth observation agencies. The state-of-the-art capabilities of these new generation SAR satellites might provide oil spill response teams with information that can be used in a tactical oil spill response role as opposed to previous SAR sensors that were only capable of a strategic role. The next generation of SAR satellites will have enhanced capabilities relative to their predecessors, these enhancements include the addition of polarimetric modes for satellites including ALOS (Advanced Land Observing Satellite), ENVISAT (ENVIronment SATellite) and RADARSAT-2. RADARSAT-2 (MDA, 2003) will be fully polarimetric, with resolutions of 11 x 9 m in polarimetric mode and down to 3 x 3 m in co- or cross-pol modes. Improved resolution and the additional information provided by polarimetric data might help discriminate between oil slicks and false targets common to radar imagery of coastal zones. The pre-launch design of RADARSAT-2 calls for the ability of the sensor to look right or left, this improved capability would reduce the time between data acquisitions over the spill location. The ASAR (Advanced Synthetic Aperture Radar) sensor (ESA, 2002) on ENVISAT follows the successful missions of the ERS-1, -2 satellites of the European Space Agency. ASAR has an alternating polarization burst mode, in which transmit and receive polarization can be selected allowing scenes to be imaged simultaneously in two polarizations at reduced azimuth resolution.

When responding to major oil spills, there are requirements for both long-term and short-term information. In terms of remote sensing capabilities, the tactical or short-term needs have traditionally been addressed by airborne sensors. A survey of marine surveillance and remote sensing organizations around the world supports this generalization (Brown and Fingas, 1999). Oil spills are inherently dynamic in nature, as the oil is influenced by the physical environment in which it is spilled and its own changing chemical composition. Prompt information about the location and extent of the spill are required to effectively direct spill countermeasures. Often information which is more than an hour old is useless except for purposes of documentation. Certain specific types of sensors are not yet available (nor will they be in the foreseeable future) on space-borne platforms. These sensors include infrared sensors and laser fluorosensors which are adversely affected by the extremely long path lengths and atmospheric absorption and scattering processes. These sensors are useful from a tactical perspective in that they can help detect and classify oil extremely well in real-time. They are not however, wide field-of-view (FOV) sensors and therefore do not provide the synoptic view of the overall spill area. In addition the detection of oil spills with these sensors is susceptible to foul weather.

Spatial resolution requirements vary, but should be considered even for massive oil spills. It is well known that spills at sea form windrows with widths often less than 10 m. A higher (better) spatial resolution than this is required to resolve the windrow, thereby enhancing the probability of spill detection. Furthermore, when considering oil spills, information is often required on a relatively short timescale in order to be useful to spill response personnel. The spatial and temporal requirements for oil spills depend on what use would be given to the data. Table 1 gives estimates of the spatial and time requirements for several oil tasks (adapted from Fingas *et al.*, 1998).

Table 1. Oil Spill Remote Sensing Requirements

Minimum Resolution Requirements			**Maximum Time During Which Useful Data Can Be Collected (hours)**
Task	**Large Spill**	**Small Spill**	
Detect oil on water	**6**	**2**	**1**
Map oil on water	**10**	**2**	**12**
Map oil on land/shore	**1**	**0.5**	**12**
Tactical water cleanup	**1**	**2**	**1**
Tactical support land/shore	**1**	**0.5**	**1**
Thickness/volume	**1**	**0.5**	**1**
Legal and prosecution	**3**	**1**	**6**
General documentation	**3**	**1**	**1**
Long-range surveillance	**10**	**2**	**1**

2 Synthetic Aperture Radar Sensors

Over the past decade a number of remote sensors have been deployed on earth observation satellites. Of particular interest is the development of SARs for deployment on satellite platforms. Oil on a sea surface dampens the small capillary waves that are normally present on clean seas. These capillary waves reflect radar energy producing a "bright" area in radar imagery known as sea clutter. The presence of an oil slick can be detected as a "dark" area or one which has an absence of sea clutter. Unfortunately oil slicks are not the only phenomenon which can be detected in similar manner. There are many potential interferences including, fresh water slicks, calm areas (wind slicks), ship wakes, wave shadows behind land or structures, vegetation or weed beds which calm the water just above them, glacial flour, biogenic oils, whale and fish sperm. This is particularly exacerbated in low wind conditions where natural surfactants can easily be confused for spills. Figure 1 illustrates a recent case where calm water produces regions of reduced backscatter (the black areas along the coast are calm water) that are very similar in appearance to oil slicks, however there were no oil slicks detected (ESA, 2003a). Extreme weather conditions such as heavy rain storms are known to affect SAR imagery, as illustrated in Figure 2 (ESA, 2003b). SAR satellite imagery has shown that several false signals are present in a large number of scenes (Wahl *et al.*, 1993; Bern *et al*., 1993). Despite these limitations, radar is an important tool for oil spill remote sensing since it is the only sensor capable of searching large areas. Radars, being active sensors operating in the microwave region of the electromagnetic spectrum, are one of the few sensors that can "see" at night and through clouds or fog. Experimental work on oil spills has shown that X-band radar yields better data than L- or C-band radar (Fingas and Brown, 1996). The benefit of using X-band relative to C-band is offset by the lower susceptibility of C-band radiation to absorption by rain. Operationally this is a strong factor in favour of C-band. Furthermore, it has been shown that antenna polarizations of vertical for transmission and vertical for reception (VV) yield better results than other configurations (Alpers and Hühnerfuss, 1989; Madsen *et al.*, 1994). Investigations have found that C-band HH polarized imagery such as that collected with the RADARSAT-1 satellite does an extremely good job on delineating oil slicks (Vachon and Olsen, 1998). Radar detection of oil slicks is limited by sea state, low sea states will not produce sufficient sea clutter in the surrounding sea to contrast to the oil and very high seas will scatter radar sufficiently to block detection inside the troughs. Indications are that wind speeds of at least 1.5 m/s (~3 knots) are required as a minimum to allow detectability and a maximum of 6 m/s will again remove the effect (Hielm, 1989; Hühnerfuss *et al.*, 1996). This limits the application of radar for oil slick detection.

In the past few years, SAR satellites have provided imagery in response to a number of large marine oil spills including the *Prestige, Erika, Sea Empress* (Figure 3), *Braer* and the *Nakhodka*. A recent example of RADARSAT-1 imagery of a fuel oil pipeline spill is shown in Figure 4. The low spatial resolution and revisit times afforded by these SAR satellites has historically relegated their use as strategic as opposed to tactical tools. Furthermore, interpretation of this imagery is highly subjective and can lead to the improper redirection of response resources. Table 2 lists the spatial resolutions, swath widths and overpass frequencies of selected space borne and airborne sensors (adapted from Fingas *et al.*, 1998).

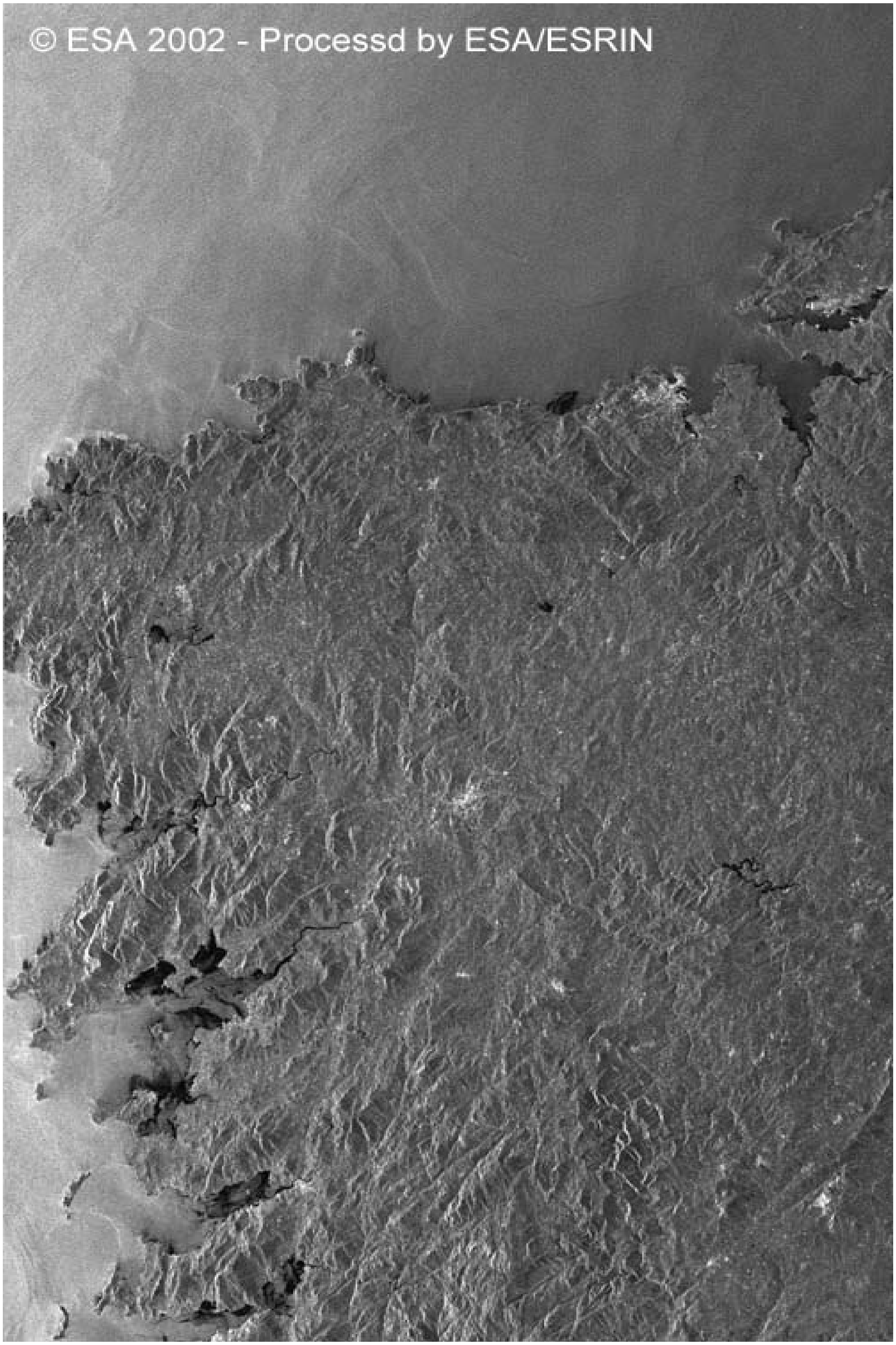

Figure 1. ERS-2 SAR (V,V) acquisition of December 12, 2002 (orbit 39978), no oil slicks were detected (the black areas along the coast are calm water).

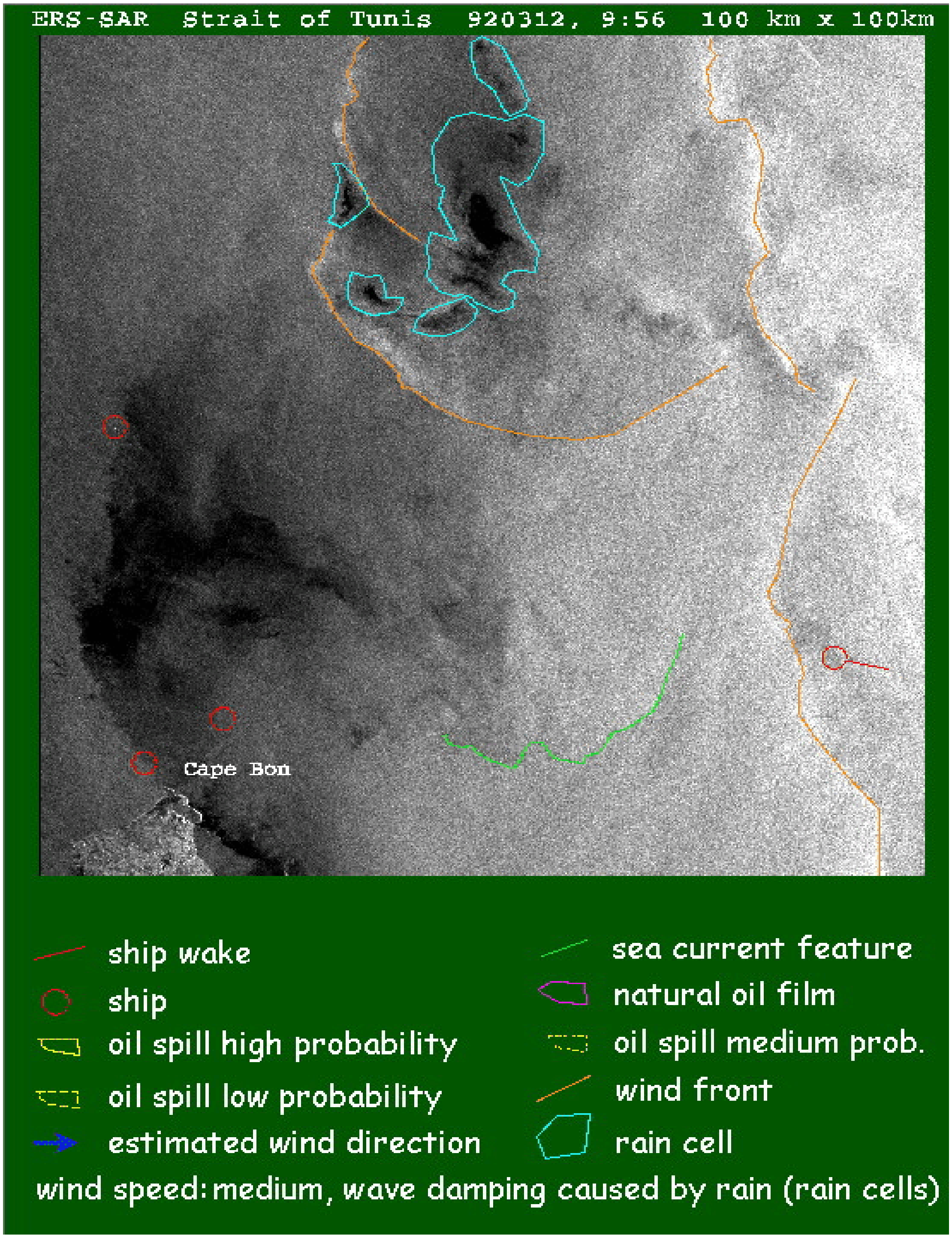

Figure 2. ERS-1 SAR image illustrating effects of heavy rain storm (upper centre of image) in the Strait of Tunis, Italy.

Table 2. Comparison of Selected Existing Satellite and Airborne Sensors

	Spatial Resolution		Swath Width	Over-pass	Full-earth	Process Time
Radar	Minimum	Range		**Frequency**	**Repeat Cycle**	**Typical**
ERS-2	30 m		100/500 km	3 days	35 days	< 2 hours
RADARSAT-1	9 m	9-100 m	50-500 km	2 days	7/17 days	< 2 hours
Airborne sensors						
Typical SLAR	10 m	10-50 m	10-40 km *	as required		real-time
Typical SAR	1-3 m	1-10 m	10-40 km *	as required		real-time
			* single-sided			

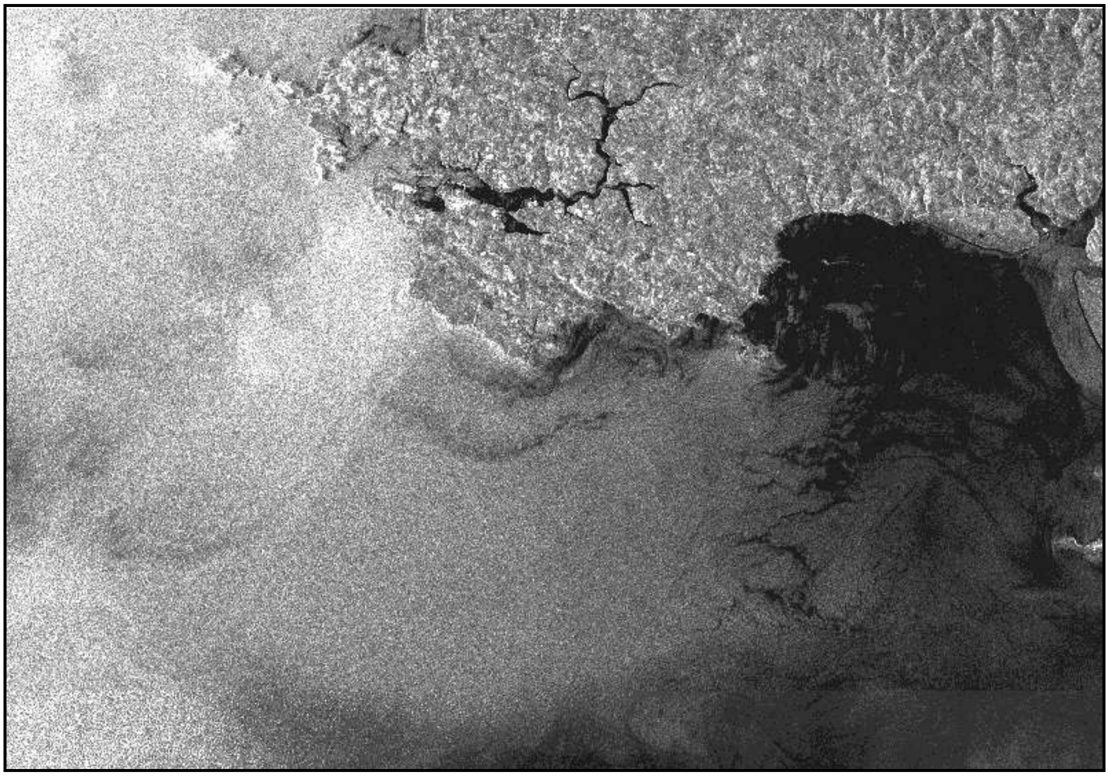

Figure 3. February 26, 1996, ERS-2 image of the Sea Empress oil spill off the coast of Wales, UK, illustrating areas of thicker oil, thinner oil and calm water (ESA, 1996).

In order to be more useful to the spill response community, the operating characteristics of space borne satellites need to more closely resemble those of airborne sensors. While this is not always technologically feasible, planned improvements in the capabilities of satellite remote sensors will narrow the gap with respect to airborne sensors. These new space-borne sensors will hopefully provide oil spill response personnel with more than just an overview of the spill scene.

Of optimum importance is the frequency of data collection, processing time and the inherent spatial resolution of the imagery provided. There are two ways to increase the frequency of data collection, one by increasing the number of satellites available and secondly by launching satellites which have sensors that can be steered or aimed at the target of interest. Technologically advanced space borne SAR sensors have recently been, or are scheduled to be launched by the European Space Agency (ASAR, C-band, on ENVISAT), Canada (RADARSAT-2, C-band) and the

National Space Development Agency of Japan (PALSAR, the Phased Array type L-band Synthetic Aperture Radar on ALOS). Each of these SAR sensors will have various degrees of steerability and provide ScanSAR mode capabilities. A ScanSAR radar illuminates several adjacent ground swaths almost simultaneously by "scanning" the radar beam across a large area in a rapid sequence. The adjacent scenes (typically 50 km in width) are then merged into a single large scene during processing. In addition to improved data frequency and spatial resolution, these SAR sensors offer enhanced polarization capabilities. One might expect the enhanced polarimetric capabilities of these new SAR sensors will help reduce the number of false targets in SAR imagery. It is possible that certain of the physical or biogenic processes which cause "slick-like" features in SAR imagery will appear different in polarimetric imagery than actual oil slicks. Experimental confirmation of this assumption will be required. The capabilities of these three SAR sensors are provided in Table 3. Examination of this table reveals the improving spatial resolution offered by these new SAR satellites is starting to approach that of airborne SAR systems. One difficulty with these advanced SAR systems is that the technology employed is state-of-the-art and has resulted in delays in the sensor production and satellite launches. Thus when the satellites are finally launched, they are not increasing the number of available satellites, as their predecessors have often ended their useful lifetimes. An example of the imagery available with these new sensors is illustrated in Figure 5 where an ENVISAT ASAR image of the oil spill resulting from the *Prestige* tanker accident is shown.

The timeliness of remotely-sensed data is extremely important from a spill response point of view. There are technical limitations related to the tasking of satellites to image a particular area on the surface of the earth. Tasking of these satellites is generally done twice daily (ie. once per satellite overpass) and this is generally a "fixed" parameter. Satellite providers are however working to reduce the amount of time required to task their satellites in the event of an emergency such as a major oil spill. For example, the "Emergency" mode on RADARSAT-2 will reportedly have a 4-12 hour programming lead time window (RSI, 2003b). Not all satellite SAR systems are operated on a commercial imaging basis, some function as vital research and development instruments. Therefore, it may not be possible to task the R&D satellites for response to spill emergencies. Efforts are being made to improve the speed with which SAR data is processed to produce final useable imagery and the speed with which it is delivered to response organizations (eg. compressed data via the Internet).

Of particular importance when responding to major oil spills is the ability to predict or model the trajectory of the slick in order to protect sensitive coastal environments. The ability to model this movement requires knowledge of the slick spatial size, quantity of oil involved, weathering properties of the oil and environmental conditions such as wind speed and direction. Satellite remote sensors can provide information for many of these environmental conditions. The movement of surface oil slicks is affected for the most part by ocean currents and to some extent by the wind (generally about 3%). This is a composite effect, with the net surface velocity being the vector sum of the two. While ocean current information can be obtained from near-shore buoy mounted sensors, this is not the case for off-shore spills. Some of this information can be interpreted from visible and SAR imagery.

The Spacecraft Engineering Department of the US Navy is developing a multi-frequency polarimetric microwave radiometer (known as WindSat) for measuring ocean surface wind speed and direction (Spacecraft Engineering Department, 2000). This sensor is to demonstrate the viability of the technique and to provide tactical information to US Navy units. If successful, there may be opportunities for civilian use of the system in the future. The WindSat radiometer will have a horizontal resolution of 25 km, with a mapping accuracy of 5 km. Wind speeds will be measured from 3 to 25 m/s (precision 1 m/s) and directions from 0 to 360 degrees (precision 10 degrees).

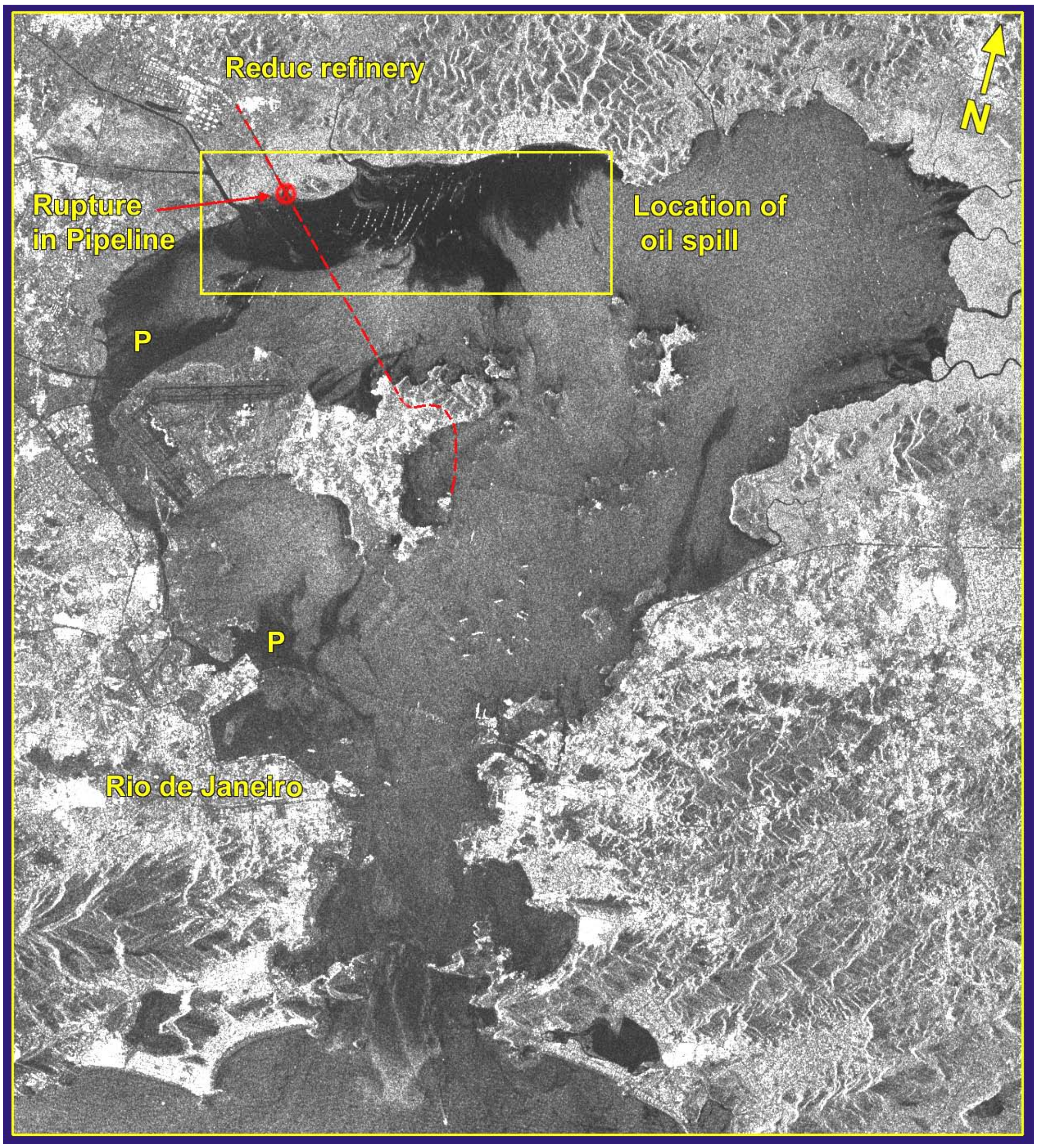

Figure 4. January 18, 2000, RADARSAT-1 image of oil refinery pipeline spill in Brazil, areas with reduced backscatter levels (P) indicate pollution from other sources (CCRS, 2003).

Table 3. Comparison Between RADARSAT-2, ENVISAT and ALOS (RSI, 2003a)

Instrument	Mode	Spatial coverage (km)	Spatial resolution (m)	Incidence angle range (degrees)	Polarization
RADARSAT - 2 C-Band	RADARSAT-1 modes	50-500	10-100	10-60	Selective Single Pol: HH or VV or HV or VH Selective Dual Pol.: HH+HV or VV+VH
	Multi-look fine	50	10	30-50	HH or VV or HV or VH
	Ultra - fine	20	3	30-40	HH or VV or HV or VH
	Standard Quad Pol.	25	25	20-41	HH+VV+HV +VH (fully polarimetric)
	Fine Quad Pol	25	10	30-41	HH+VV+HV +VH (fully polarimetric)
ENVISAT ASAR, C-band	Image	56-100	30	15-45	HH or VV
	ALTPOL	56-100	30	15-45	HH/VV or HH/HV or VV/VH
	Wide	400	150	15-45	HH or VV
	Global	400	1000	15-45	HH or VV
ALOS PALSAR, L-Band	Fine	70	10	10-51	HH or VV or HH+HV or VV+VH
	SCANSAR	250-350	100	10-51	HH or VV

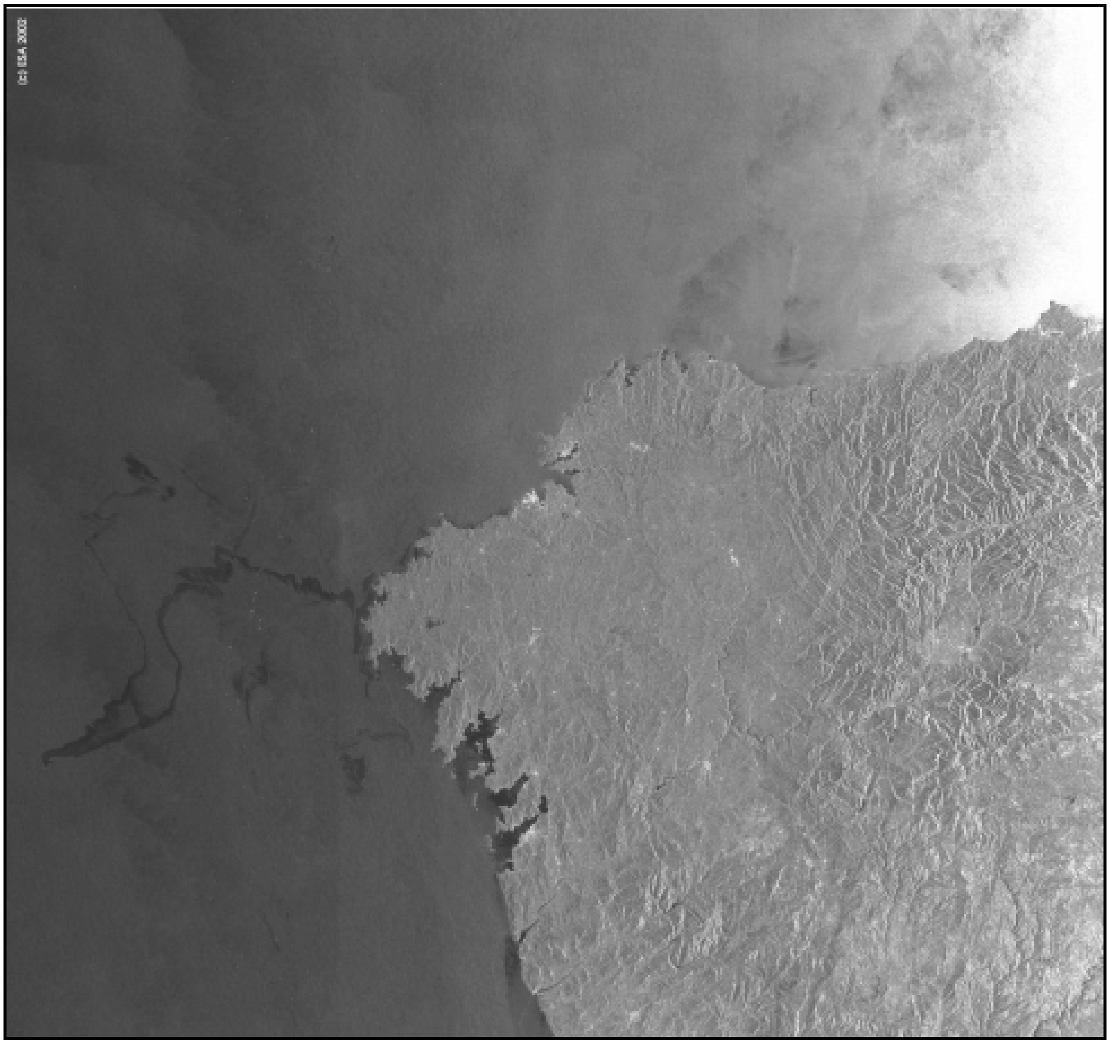

Figure 5. November 17, 2002, ENVISAT ASAR wide swath image of the oil spill from the Prestige oil tanker off the coast of Spain (ESA, 2003c).

3 Conclusions

Recent, and soon to be launched space borne synthetic aperture radar sensors will provide oil spill response personnel with improved spatial resolution and more timely information rather than just a synoptic overview of the spill scene. The state-of-the-art capabilities of these new SAR satellite sensors should provide responders with information that, in theory, can be used for the tactical remote sensing of oil spills. In order to be fully functional in a tactical response, the number of available SAR satellite systems needs to be increased significantly. Additionally, alternate platforms such as the International Space Station (ISS) should be considered for SAR sensors. It doubtful that space borne SAR sensors will supplant airborne oil spill remote sensors in the foreseeable future, therefore a continued synergy between airborne and space borne sensors is envisioned.

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